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Cold Regions Research and Engineering Laboratory

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Engineering for Polar Operations, Logistics, and Research (EPOLAR)

Shelter Deployment at Former Army Camp Tuto, Greenland

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Under Engineering for Polar Operations, Logistics, and Research (EPOLAR)
EP-ARC-11-17, “Inflatable Airbeam Structure”

Abstract

On behalf of the National Science Foundation, the Cold Regions Research and Engineering Laboratory (CRREL) and the Natick Soldier Research, Development and Engineering Center (NSRDEC) collaborated to test a commercially produced, expedient shelter to assess whether it could meet needs for reusable storage space, temporary lodgings, or other infrastructure uses in extreme cold-weather locations. We obtained an inflatable shelter and deployed it on a frozen lake near former Army Camp Tuto in northwest Greenland. The shelter consisted of pressurized "airbeams" supporting a stretched-fabric skin, and we securely anchored it into the ice. Although nominally rated to withstand 65 mph wind gusts and −25°F air temperatures, the shelter disintegrated during a storm when these conditions occurred concurrently. The skin fabric succumbed to cold cracking from the combination of extreme cold temperatures and flapping during high winds. The airbeams were more durable, and we recovered them intact and still inflated. These results suggest that additional development and testing is needed to ensure that expedient shelters developed for less demanding environments can survive the extreme conditions commonly encountered in Polar Regions.

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Preface

This study was conducted for the National Science Foundation (NSF), Division of Polar Programs, Arctic Research Support and Logistics under Engineering for Polar Operations, Logistics, and Research (EPOLAR) EP-ARC-11-17, "Inflatable Airbeam Structure." The technical monitor was P. R. Haggerty, Program Manager, Arctic Research Support and Logistics.

The work was performed by Christian Aall, Fabric Structures Team, U.S. Army Natick Soldier RD&E Center (NSRDEC), and by Dr. James Lever, Dr. Jennifer Mercer, and Jason Weale (Force Projection and Sustainment Branch, Edel Cortez, Chief), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Dr. Justin Berman was Chief of the Research and Engineering Division. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

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The Commander of ERDC is COL Jeffrey R. Eckstein, and the Director of ERDC is Dr. Jeffery P. Holland.

Acronyms and Abbreviations

AB	Air Base
CPS	CH2MHill Polar Services
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
EPOLAR	Engineering for Polar Operations, Logistics, and Research
ERDC	Engineer Research and Development Center
GrIT	Greenland Inland Traverse
NSF	The National Science Foundation
NSRDEC	Natick Soldier Research, Development and Engineering Center
TEMPER AS	Tent, Extendable, Modular, Personnel, Air-Supported

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
square inches	6.4516 E-04	square meters

1 Introduction

In early 2009, the Cold Regions Research and Engineering Laboratory (CRREL) communicated its need for an extreme-weather-hardened, rapidly deployable shelter to support the National Science Foundation (NSF) in their annual Greenland Inland Traverse (GrIT). This over-snow traverse resupplies NSF's Summit research station from a staging area outside Thule Air Base (AB) near former Army Camp Tuto. In addition, NSF expressed an interest in rapidly deployable shelters at Summit to billet researchers or to maintain vehicles. Natick Soldier Research, Development and Engineering Center (NSRDEC) responded to this request by offering a proven military soft-walled shelter system for cold-weather evaluation.

NSRDEC supplied a rapidly deployable, 32 × 20 ft TEMPER AS (Tent, Extendable, Modular, Personnel, Air-Supported) expedient shelter system (manufactured by Vertigo/HDT Engineered Technologies). This shelter consisted of a fabric outer skin supported on inflatable arches called "airbeams." It was verified by the manufacturer to withstand 55 mph continuous wind speeds and up to 65 mph gusts for 10 minutes. Additionally, the shelter skin fabric and airbeams underwent government-sanctioned extreme-cold testing and met requirements by showing no noticeable degradation at −25°F (−32°C). These tests were performed in accordance with MIL-PRF-44271C.

At the request of NSF and its primary Arctic support contractor, CH2MHill Polar Services (CPS), NSRDEC modified an end-wall panel so that the shelter would accommodate small support vehicles used by researchers at Summit. The end-wall modification provided vehicle-maintenance and storage capability for vehicles less than 7 ft tall and 8 ft wide. The necessary modifications were performed at NSRDEC's Tent Prototyping Facility.

To reduce heat loss in extreme cold temperatures, NSF also requested that a thermal liner be shipped with the shelter system although, due to time and airlift constraints, the shipped system did not include an environmental control unit.

On 1 March 2011, with the shelter system, thermal liner, and other associated support/setup equipment (Table 1), representatives of NSRDEC, CRREL, and CPS departed Stratton Air Base, Scotia, NY, for Thule, Greenland, on a Hercules LC130.

Table 1. Supplies brought to Greenland for testing.

Crate 1: Shelter system	
Included in the crate	Airbeam shelter Lights Vestibule Stakes
Weight	862 lb
Wooden Shipping Crate Weight	214 lb
TOTAL Weight	1076 lb
Size	84 × 48 × 48 in.
Crate 2: Additional components	
Included in the crate	Thinsulate thermal liner
Weight	159 lb
Wooden Shipping Crate Weight	123 lb
TOTAL Weight	282 lb
Size	59 × 36 × 36 in.
Crate 3: Air compressors	
Included in the crate	2 air compressors
TOTAL Weight	250 lb
Size	48 × 24 × 24 in.

2 Preparation

2.1 Practice deployment

The crates containing the shelter system and associated hardware were transported from the LC130 into a large aircraft hangar (Hanger 8) at Thule AB. In preparation for deployment of the shelter, we performed a trial setup as a training opportunity for personnel responsible for the actual remote deployment. This preparatory event also permitted a test fit and pre-installation of the thermal liner.

Because of the concrete floor, we developed an improvised anchoring system for the trial deployment. This system consisted of come-along straps tightened around the base of several heavy crates as depicted in Figure 1.

Figure 1. Anchor points used in trial shelter deployment.

These anchor points were sufficiently rigid to erect the shelter system and to apply tension to the guy lines. During inflation, there were minor leaks detected in the manifold system, preventing the shelter system from fully deploying. Upon further inspection, we noted that a fitting for the pressure relief valve was misaligned during assembly at the manufacturer's facility, creating a relatively large moment arm that would twist itself when the shelter was rolled up for transport (Figure 2). This issue was quickly addressed and resolved.

Figure 2. Misaligned valve and disassembly prior to repair.

We ceased airbeam inflation upon reaching 45 psi. At this point, the airbeam frame component of the shelter was rigid. Because the improvised anchor points began to shift as the ratchet straps were further tightened down, the shelter fabric appears saggy in Figure 3 though this was acceptable for indoor trial and training purposes.

Figure 3. Shelter system erected in Hangar 8 on 5 March 2011.

2.2 Liner pre-installation

To reduce the amount of time required to complete the shelter deployment in extreme weather conditions, we installed the thermal liner during the indoor trial. Additionally, the pre-installation allowed us to determine how much bulk the thermal liner added to the rolled up shelter system and whether the liner might incur damage during setup, strike, or transport while it remained installed in the shelter.

Camel Manufacturing, the contractor responsible for integrating the Thinsulate material into a thermal liner, opted for a novel approach in fastening the liner to the shelter interior. By using a sleeved pin pushed through a loop, one could easily attach and remove the liner by pushing the T-shaped assembly through a grommet on the liner straps (Figure 4).

Figure 4. The sleeved-pin assembly pushed through a liner grommet and the installed liner.

After liner installation and a thorough shelter inspection, the shelter was "struck." First, we opened the air release valves and then vacuumed air out of the airbeams. Finally, we rolled up and ratchet strapped the complete assembly for transport to the remote test site. The shelter system with the installed thermal liner rolled up into a cylinder shaped bundle (Figure 5) that was no more than 6 in. larger in diameter than the shelter rolled up without a liner.

Figure 5. Rolled-up and ratchet-strapped shelter with liner installed.

2.3 Weather-station construction

Simultaneous to our preparing the shelter for test site deployment, we completed the assembly of a weather station. The intent of the weather station was to record video and environmental factors, which we could analyze later, for the shelter-test duration.

The weather station hardware consisted primarily of Campbell Scientific data acquisition equipment, designed to operate and acquire data in harsh environmental conditions while having enough memory capacity to record several weeks of data without human interaction. This autonomous capability was important because of the rapidly changing weather conditions, potentially confining personnel to the dormitories.

In addition to the standard Campbell Scientific sensor arrangement, there were several third-party sensors, a battery bank, a video camera, and solar panels installed onto the weather station. Throughout the test duration, the station recorded simultaneously temperature, humidity, wind speed and direction, and video footage while sharing a time stamp to ease correlation during analysis of the data at a later date. Figures 6 and 7 depict the weather station tri-pod frame and associated accessories.

Figure 6. Weather station video camera, temperature and humidity sensors, and control box.

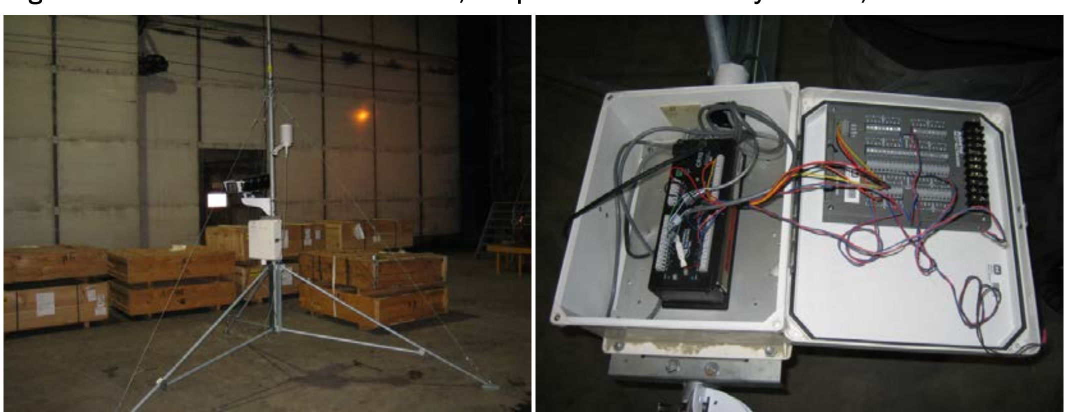
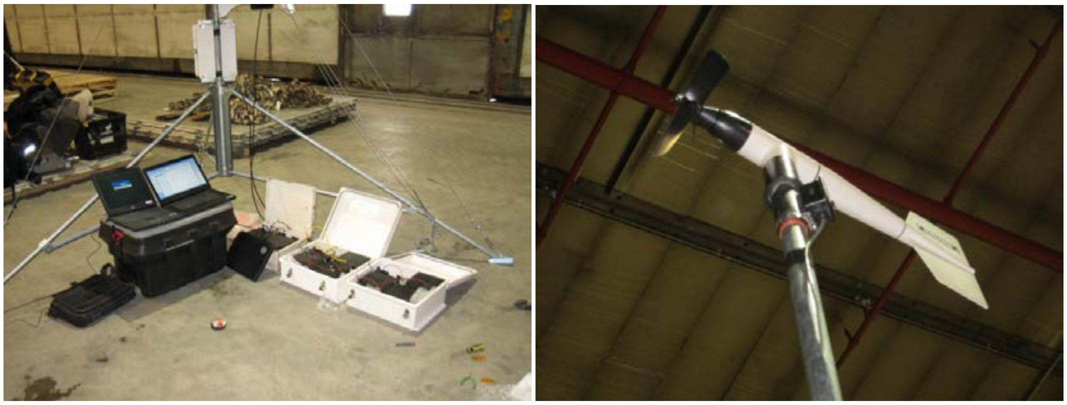


Figure 7. Battery boxes and anemometer.



3 Test Site Deployment

3.1 Location

We chose the location to deploy the shelter, near former Army Camp Tuto, because of its consistently strong winds, extreme cold temperatures, and proximity to GrIT's staging area near the ice cap. An added benefit of this location was the predictable direction of strong winds, which blow from a southeasterly direction, directly off the ice cap and towards Thule AB. This consistent wind direction allowed us to orient the shelter in such a fashion that the front-facing end wall would experience the entire inflicted wind load directly normal to its surface. We selected this orientation as the catalyst for a worst case scenario: a large surface area acting as a sail and exerting several thousand pounds of force onto the shelter guy line anchors. Catastrophic failure mode would likely result in guy-line shelter attachment points failing, causing the whole shelter system to lift and incur severe structural damage.

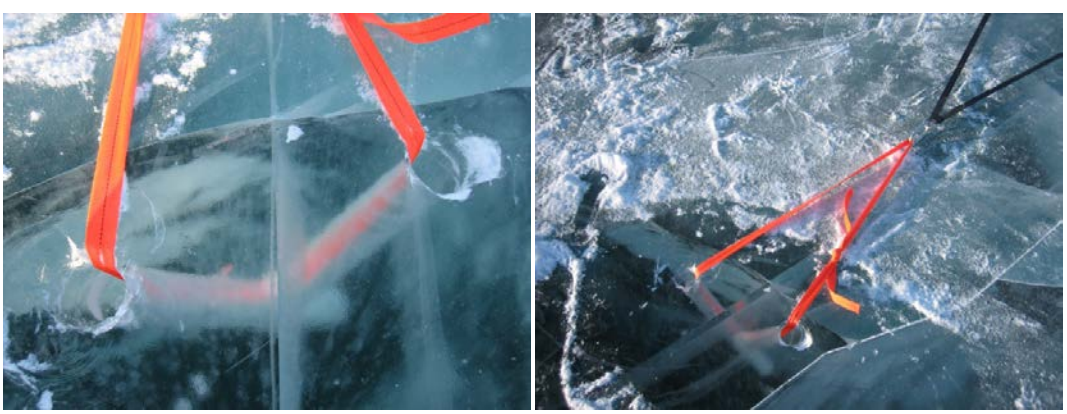
3.2 Shelter anchoring

We deployed the shelter on 9 March 2011. We chose a frozen lake as the deployment site to facilitate durable anchoring with drilled V-threads. Initially, we unrolled and flattened out the shelter on the ice (Figure 8), taking great care by pulling on guy lines simultaneously to ensure that the shelter was square. We encountered some difficulty during the process of squaring off the shelter, which can be attributed primarily to fabric stiffness from "over-nighting" the bundled-up shelter outdoors at −30°F (−34°C). Finally, we laid out the guy lines in a squared-off fashion to assist in properly locating the anchor points.

Figure 8. Unrolled and squared-off shelter, deployed 9 March 2011 on a frozen lake.

We chose V-threads primarily because of their strong horizontal- and vertical-pull direction holding strength. Resistance to both pull directions was important in case of high winds creating significant loads on the diagonal guy lines. A V-thread is set into the ice by means of a 2 in. diameter auger. The approach angle of the drilled holes usually meet at a 90° angle, and it is important that the second hole be drilled in the same plane as the first to facilitate an intersection below the ice. Webbing is then fed through one hole while the auger is manually used to pull it through the second hole. Finally, the webbing is tied off after having been fed through the metal “eyelet” on the guy lines (Figure 9).

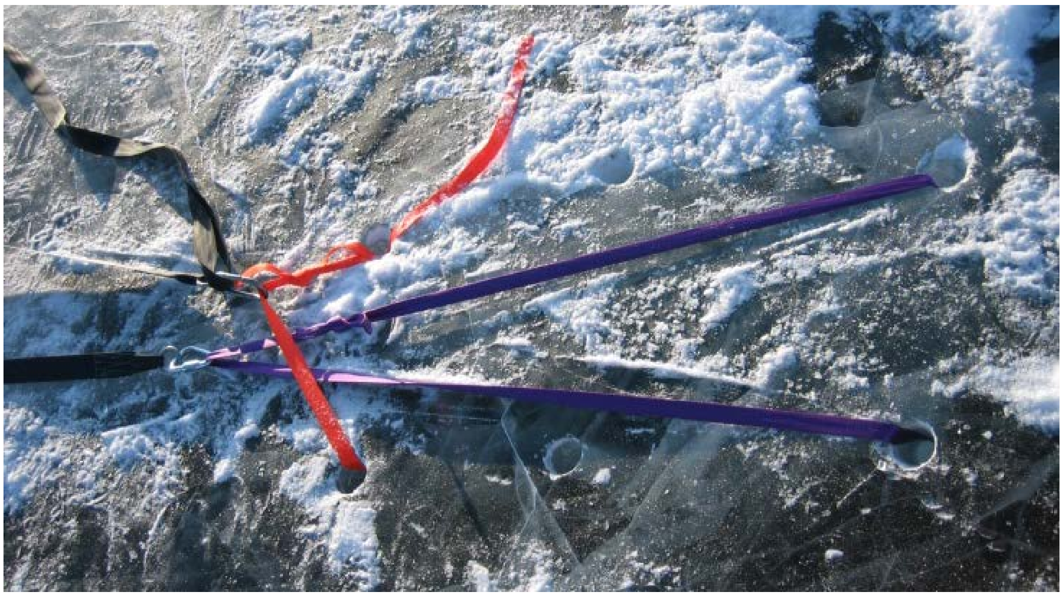
Figure 9. The V-thread anchor configuration, showing drilled holes and tieing off to the guy lines.



The rear section of the shelter, with the modified end wall, had separate attachment points for the diagonal and horizontal guy lines. To ensure that

the diagonal guy line would not pull the horizontal guy line away from the ice at the anchoring point, we decided to incorporate two anchor points to split the loads into their directional components. Separate anchor points allowed the horizontal guy line to remain parallel and touching the ice, while being unaffected by the angled pull force of the diagonal guy line (Figure 10).

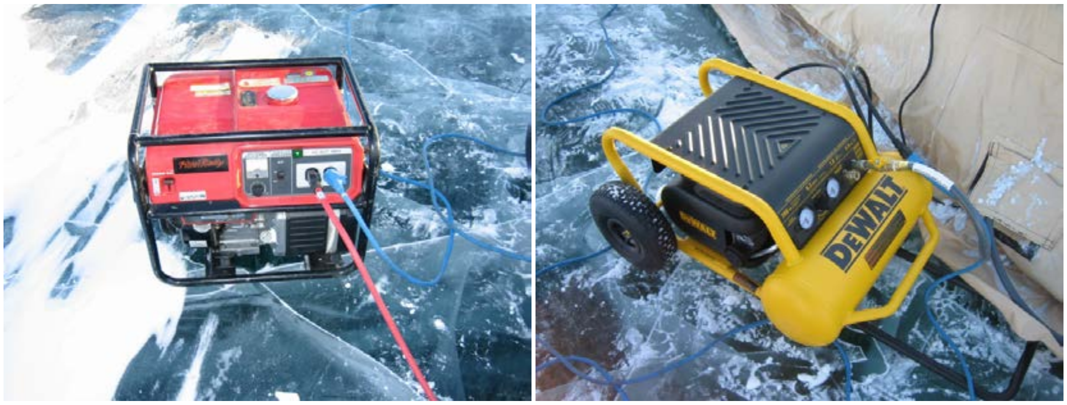
Figure 10. Separate anchors for diagonal and horizontal guy lines (red and purple webbing, respectively).



3.3 Shelter airbeam-frame inflation

Inflation of the airbeam structure was facilitated by a 1.8 hp Dewalt air compressor connected to a Honda 2500 W generator running off of JP-8 diesel fuel (Figure 11). Both the compressor and generator maintained 100% operability at −20°F ambient. The air compressor's pressure regulator was set by the shelter manufacturer to shut off at approximately 45 psi. This value was specified in the shelter operating manual as the required inflation pressure to maintain maximum wind load and deflection resistance.

Figure 11. The 2500 W generator and 1.8 hp air compressor.



Once the air compressor achieved the target pressure level, we shut it off and closed the air manifold valves on the shelter. We then further tensioned the front and rear main guy lines to stretch the shelter fabric into shape. We encountered some difficulty during the tensioning process. Regardless of the amount of tension that we applied by tightening the ratchet straps, the fabric refused to ease into a tensioned state and smooth out (Figure 12). Most likely this was due to the fabric having become too stiff and rigid from being overnighted in a “packed state” while at −30°F.

Figure 12. Fabric droop experienced due to stiff shelter-skin fabric.

In addition to the front and rear main guy lines, the shelter also came equipped with eight high-wind lines, four along either side of the shelter. We anchored each high-wind line into the ice in a similar V-thread fashion as the main guy lines. Hand-pulls located on the rope allowed for the appropriate pre-tension to secure the wind lines and to ensure proper functionality. We anchored down the grommets along the perimeter skirt by means of lag bolts screwed into slightly undersized holes drilled in the ice with a portable electric drill.

The total time required to completely deploy and anchor the shelter system into the ice was around four and a half hours. The deployment required three people to properly align the shelter in its non-inflated state prior to drilling the anchors. The individual performing the anchoring was a skilled mountaineer very experienced in anchoring in ice by the means of V-threads and lag bolts. Early in the course of the deployment, the two other individuals present were trained in properly aligning and setting V-threads, allowing them to share the workload for this most time-consuming task. After the main guy lines were anchored to the ground, only two people remained to complete the side high-wind line anchors and skirt lag bolts.

3.4 Weather-station deployment

On 9 March 2011, we also deployed and anchored into place the weather station at a location 100 ft up-wind of the shelter (Figure 13). The three guy lines (situated between the three tripod legs) were strapped into place using V-thread anchors. We also screwed in lag bolts around the “feet” of the tripod legs to mitigate the tripod moving on the ice during high wind conditions. We wired several battery banks into the digital video camera and Campbell Scientific data logger unit; and with small webbing fed through V-thread anchors, we strapped to the ice the cases containing these batteries.

Figure 13. Preparation and deployment of the weather station on 9 March 2011.

4 Results

4.1 Data collected

The Campbell Scientific data logger collected data from the beginning of shelter deployment on 9 March 2011 until the test site was broken down on 22 March 2011. Data were then downloaded to a computer, analyzed, and formatted into graphs as shown in Figures 14–16. The Campbell Scientific data logger sampled every 5 seconds and recorded every 5 minutes the average and maximum (gust) wind speeds, average air temperature, and average wind direction.

Figure 14. Graph depicting ambient temperature during the shelter deployment.

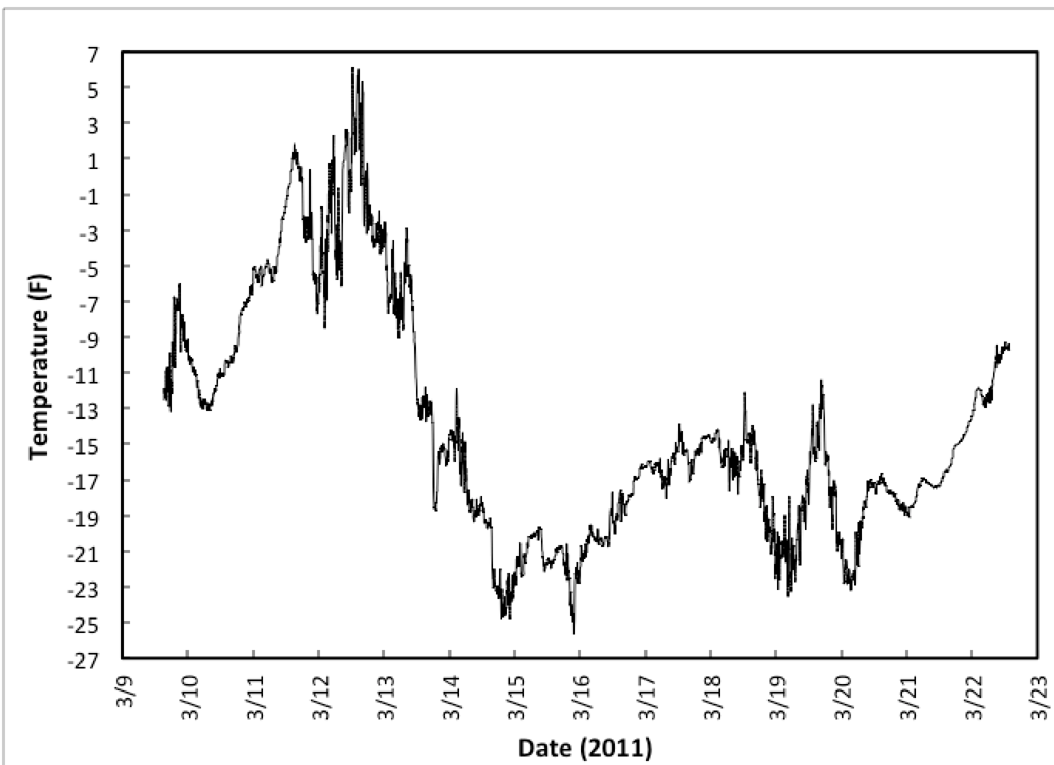


Figure 15. Graph depicting wind speed and wind gust during the shelter deployment. Note the high winds over the storm period 20–22 March 2011.

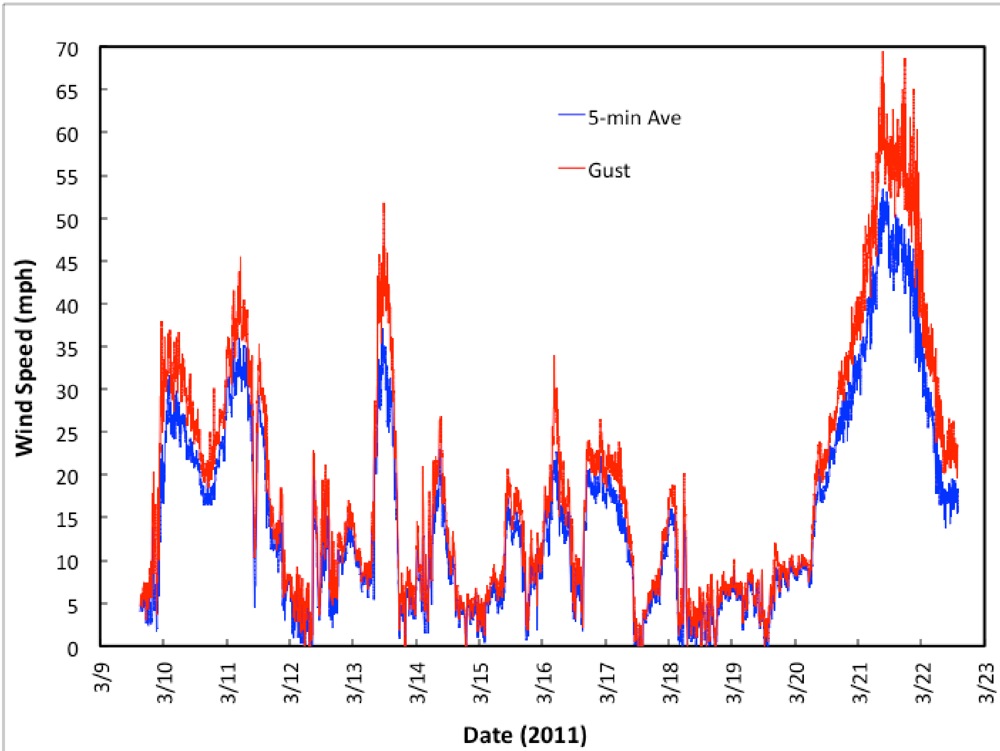
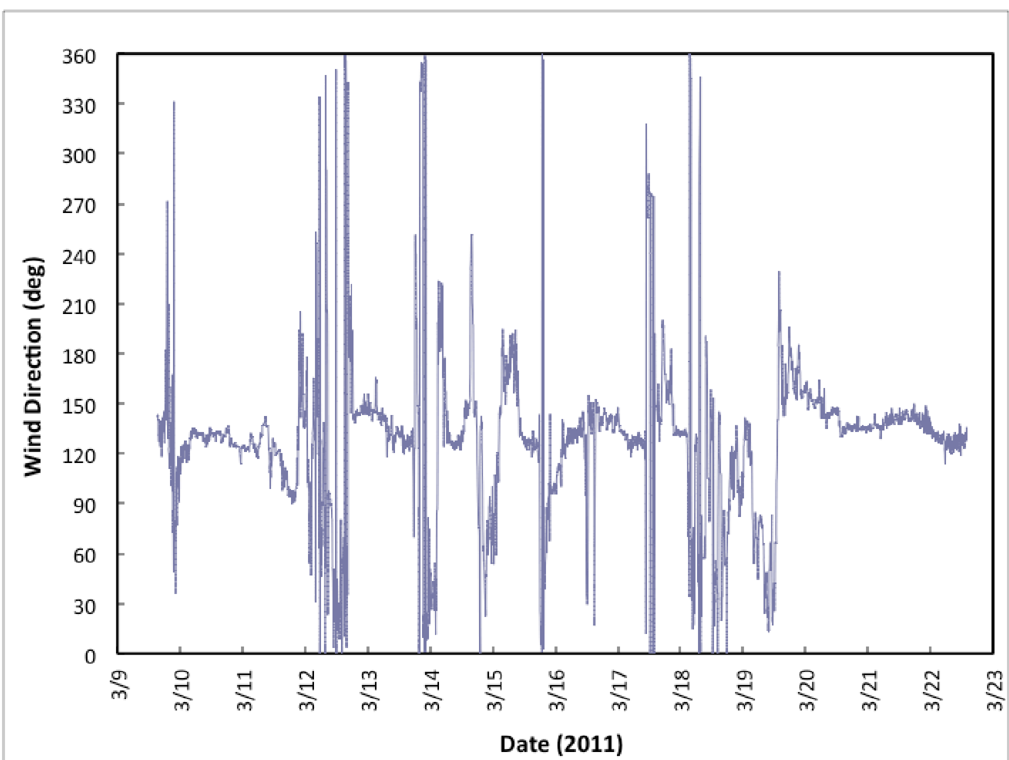


Figure 16. Graph depicting wind direction during the shelter deployment. Winds during the storm period 20–22 March 2011 were from the southeast, essentially directly against the front of the shelter.



4.2 Shelter performance

The shelter initially performed well during moderately high winds (average > 30 mph, gusts > 40 mph) on 11 March and 13 March. After this period, air temperatures dropped below –10°F for the remainder of the deployment. The shelter was still intact on 19 March 2011, but the outer skin continued to droop despite repeated efforts to tighten the guy lines (Figure 17). Close inspection revealed the presence of fine cracks in the outer skin (Figure 18), which likely resulted from flapping of the loose fabric.

Figure 17. Shelter intact on 19 March 2011 but with drooped and wrinkled outer skin despite tight guy lines.

Figure 18. Evidence of fabric cold cracking observed on 19 March 2011.

A storm began on 20 March 2011, and we were confined to our dorm for the ensuing two days, owing to high winds and low visibility. During this storm, wind speeds at the shelter exceeded 50 mph with gusts approaching 70 mph. Air temperatures were below –17°F during the period of highest winds on 21 March 2011.

Winds diminished, and we were able to return to the site on 22 March 2011. It was immediately clear that the storm had destroyed the shelter. The outer skin had shredded, and 80% of the structure had been blown away by the wind (Figure 19).

Figure 19. Remains of the shelter after the 20–22 March 2011 storm. Anchored guy lines retained the front and rear airbeams, but most of the outer skin and the two middle airbeams were blown far downwind.

We determined that the failure was not due to user delinquency in airbeam maintenance or the use of inappropriate anchoring methods. Throughout the evaluation, operational airbeam pressures remained 45–50 psi, and V-thread anchors remained 100% intact. Sufficient evidence exists showing that the shelter skin fabric succumbed to cold cracking from the combination of extreme cold temperatures and flapping during high winds (Figure 20). Total failure probably occurred at a rapid pace whereby cracked fabric in the tension load-bearing shelter skin tore abruptly in high winds, shearing the shelter system from its anchored front and rear airbeams. Only the front and rear airbeams and their associated end-wall fabric remained attached to the guy lines and anchors in the ice. We found the two remaining airbeams at the downwind end of the frozen lake. Both were still pressurized (inflated) with no damage sustained. Unfortunately, the video record ended (memory full) with the shelter still intact a few hours before the period of peak winds, so we cannot identify the exact sequence of shelter destruction.

Figure 20. Recovered piece of shelter outer skin showing cold cracking and torn fabric.

5 Conclusion

NSRDEC plans to develop a test procedure through which shelter fabrics may be exposed to similar conditions as experienced during the aforementioned shelter failure while remaining in a laboratory environment. A Gelbo flex test is a possible method to simulate the buffeting and tensioning of shelter skin fabrics while deployed in windy environments. The Gelbo flex test, originally designed to evaluate boots, allows for fabrics to be evaluated under compound stressing. It does so by enacting an axial tension load on the cylindrically-wrapped fabric sample while simultaneously counter-rotating either end of the fabric cylinder to induce the compound stresses that often result in composite fabric disassociation.

To further increase the viability of the simulation, the testing equipment along with fabric samples will remain in an extreme-cold environment for the duration of the test. The objective is to induce similar cold-cracking failure modes as experienced in the Greenland shelter deployment. Several fabric samples from different vendors will be evaluated against the Greenland shelter baseline to determine the fabric composition that is the most survivable polar-climate shelter-fabric solution.

In conjunction with performing in-house testing and evaluation of shelter fabrics, NSRDEC and CRREL await industry proposal submissions against SBIR topic “A11-099: Rapidly Deployable Lightweight Shelters for Austere Environments,” co-authored by the partnered research installations. The resultant prototypes will be evaluated on both a component-level simulation and a full-scale deployment. The requirements set forth are that the shelter must survive 100 mph gusts and −50°C and be rapidly deployable. NSRDEC and CRREL intend to keep NSF and all other supporting agencies informed of future efforts toward a polar-region-hardened structure that is expedient in nature.

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14. ABSTRACT
On behalf of the National Science Foundation, the Cold Regions Research and Engineering Laboratory (CRREL) and the Natick Soldier Research, Development and Engineering Center (NSRDEC) collaborated to test a commercially produced, expedient shelter to assess whether it could meet needs for reusable storage space, temporary lodgings, or other infrastructure uses in extreme cold-weather locations. We obtained an inflatable shelter and deployed it on a frozen lake near former Army Camp Tuto in northwest Greenland. The shelter consisted of pressurized “airbeams” supporting a stretched-fabric skin, and we securely anchored it into the ice. Although nominally rated to withstand 65 mph wind gusts and −25°F air temperatures, the shelter disintegrated during a storm when these conditions occurred concurrently. The skin fabric succumbed to cold cracking from the combination of extreme cold temperatures and flapping during high winds. The airbeams were more durable, and we recovered them intact and still inflated. These results suggest that additional development and testing is needed to ensure that expedient shelters developed for less demanding environments can survive the extreme conditions commonly encountered in Polar Regions.

15. SUBJECT TERMS

Durability	Extreme cold weather	Polar Regions
EPOLAR	Inflatable shelter	Rapidly deployed buildings
	NSF	Survivability

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